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# Military Use of Commercial SATCOM: Benefits, Costs and Challenges

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**Abstract.** This paper discusses several aspects of the United States military's use of commercial satellite communications. Although much of the discussion applies to all of the uniformed services, the focus here is on the Department of the Navy which is the largest user of commercial satellite communications resources in the Department of Defense. A diverse set of references is provided for readers interested in further exploration.

## Introduction

Military needs in the Cold War era were the catalysts for the birth of the space industry and served as the principal drivers for the development of space-based communications technologies starting in the late 1950's[1]. With the end of the Cold War and increased commercial demand for communications services, military needs today are driving a shrinking minority of the technological breakthroughs in satellite communications (SATCOM). This trend, and reduced spending across-the-board by the Department of Defense (DoD), have caused those charged with providing communications for the uniformed services to give unprecedented consideration to using commercially available equipment, software and service leases. Indeed many of the new military SATCOM (MILSATCOM) systems that DoD is deploying and planning are adopting more commercial business practices, and technologies that were originally developed for commercial markets [2].

### *Modern Naval Forces*

Two of the DoD's four uniformed services comprise the Department of the Navy (DoN): the Navy (USN) and the Marine Corps (USMC) [3]. Since 1990, with the demise of a bipolar world (US vs. USSR), there has been a redirection and expansion of the traditional expeditionary role of US naval forces [4]. Today, naval forces are the primary providers of forward presence and crisis response. They are capable of conducting operations in support of foreign policy objectives [5] from the sea without host nation support. Because of their self-sufficient nature, "naval expeditionary forces provide unobtrusive forward presence which may be intensified or withdrawn as required on short notice." [6] In the absence of a clear threat from a single opposing global superpower, the DoN's principal focus has shifted away from operations in open oceans towards "influencing events in the littoral regions of the world." [7] This has had the effect of increasing the exposure of naval ships to threats from sea mines and anti-ship cruise missiles (e.g., Silkworm, Exocet). Several design characteristics of USN's newest operational ship class, the *USS Arleigh Burke* (DDG 51) guided missile destroyer, were driven by the anti-ship cruise missile threat. These include all-steel construction and the use of radar cross section (RCS)[2] reducing geometries and coating materials topside [8]. Future naval construction will take RCS reduction even further, placing greater restrictions on the clutter of topside hardware, including radar and communications antennas. "The ability to shape events and respond by maintaining forward-deployed, combat-ready forces is a distinctly naval contribution to peacetime engagement." [9] In making this contribution, today's sailors and marines are spending more time deployed at sea under increased threats from the proliferation of sophisticated weaponry.

### *Modern Joint Warfare*

With recent significant reductions in personnel levels, it has become all the more crucial that the Army, Navy, Marines and Air Force be capable of operating together as a cohesive joint force.[3] The modern joint approach seeks to "combine doctrine with technological advances in mobility, fire support, communications and navigation to rapidly identify and exploit adversary weaknesses across the entire spectrum of conflict." [10] DoD identifies the critical enablers of this strategy to be "quality people, a globally vigilant intelligence system, a global communications architecture, superiority in space and control of the sea and airspace." [11] In short, providing *information superiority*[4] to people who are well trained to exploit it is perceived as the key to successful joint military operations in the "information age."

### *Naval Forces in Modern Joint Warfare*

To contribute effectively in joint operations, regardless of where they may occur, naval forces must be "plugged-in" to the same information networks used by their Army, Air Force and Allied colleagues. Yet the forward-presence role of naval forces makes their communications requirements unique among the uniformed services. Aircraft Carrier Battle Groups (CVBG) and Amphibious Ready Groups (ARG) at sea cannot rely upon a terrestrially-based communications infrastructure. Only SATCOM can provide the high-capacity links to forward-deployed naval forces that enable them to be significant players

[1] The Soviet Union's launch of Sputnik on October 4, 1957, inaugurated the "space race" between the US and USSR. [1]

[2] RCS is a great concern for modern warships because many anti-ship cruise missiles rely on a self-contained active radar to lock on to the targeted ship during the terminal phase of flight.

[3] "Jointness" extends to operations with our Allies.

[4] "The capability to collect, process and disseminate an uninterrupted flow of information while exploiting or denying an adversary's ability to do the same." [12]

in joint operations. However, the sum of the capacity of all of the military communications satellites currently on orbit falls short of that needed by the DoD to carry out all of its missions. As a result, the entire DoD, and especially the DoN, have made, are making, and will continue to make significant use of commercial SATCOM to fill the capacity gaps. The remainder of this paper discusses the use of commercial SATCOM in the MILSATCOM architecture, past, present and future.

## MILSATCOM Architecture

The diversity of DoD's user populations and their information needs precludes a "one size fits all" approach to MILSATCOM. This section presents an overview of the MILSATCOM architecture which is well described as a "system of systems."

### *MILSATCOM Requirements*

It is useful to group military SATCOM requirements into three broad categories [35]:

- Narrowband,
- Wideband, and
- Protected.

The breakpoint between the narrowband and wideband categories is defined as 64 kbps. The characteristics of a "protected" circuit include (1) insusceptibility to denial by an adversary (anti-jam - AJ), (2) low probability of unauthorized detection, interception and exploitation (LPD, LPI and LPE), (3) immunity to information warfare attack (e.g., software viruses, malicious Java scripts) and (4) survivability in the presence of the atmospheric effects of nuclear weapons (e.g., fading, electromagnetic pulse - EMP).

### *Architecture Components*

Today's military SATCOM architecture uses five components to satisfy the three requirement categories [13], [35]:

- Military UHF SATCOM (~240 - 320 MHz),
- Military SHF SATCOM[5] (X-band: 7.90-8.40 GHz, 7.25-7.75 GHz),
- Military EHF SATCOM (Q/K-bands: 43.5-44.5 GHz, 20.2-21.2 GHz),
- The Global Broadcast Service (GBS), (Various non-government Ku-bands; government Ka/K-bands: 30.0-31.0 GHz, 20.2-21.2 GHz), and
- Commercial SATCOM (Various government and non-government bands: UHF, L, C & Ku past, present and future; non-government Ka/K-bands expected to be added in the future).

Thus the MILSATCOM architecture explicitly acknowledges the role of commercially-owned SATCOM systems in augmenting DoD-owned SATCOM capacity.

[5] Where two bands are given, the first is the earth-to-space (uplink) and the second is the space-to-earth (downlink).

### *Discussion*

Table 1 shows the mapping between the requirement categories and the architecture components. With regard to UHF SATCOM, what Table 1 doesn't show is this band's unique (among the bands listed) ability to penetrate very heavy rainfall and triple canopy jungle foliage. Furthermore, in the USN, UHF SATCOM is a "least common denominator" in that all ships have at least some form of UHF SATCOM capability. But UHF SATCOM is completely unprotected (except for encryption) and fraught with electromagnetic interference (EMI) problems that stem from (1) the band's use by commercial interests in some regions of the world, and (2) the UHF satellites' earth coverage beams. Nonetheless, many military planners have met recent proposals to migrate their narrowband circuits out of the 240-320 MHz band into L-band (1-2 GHz) with resistance. It appears unlikely that DoD will (willingly) suspend its use of this band any time soon.

Whereas military EHF SATCOM robustly provides all of the protection characteristics listed above, military SHF SATCOM possesses lesser AJ, LPD, LPI, LPE capabilities and less immunity to nuclear weapons effects. *All* SATCOM systems used by DoD, both military and commercial, must be protected from information warfare attacks by robust network security technologies and procedures [44], [50], [51].

For a current and thorough discussion of the MILSATCOM architecture, the reader is referred to [35]. It contains "the long-term over-arching requirements for MILSATCOM essential to achieving the promise of information superiority."[6] Indeed, the Joint Chiefs of Staff (JCS) Joint Requirements Oversight Council (JROC) approved [35] on 6 April, 1998 and "validated its capstone key performance parameters."[7] These "KPPs" are the following:

- Coverage,
- Protection,
- Interoperability,
- Flexibility.
- Capacity,
- Access & Control,
- Quality of Service, and

Historically, currently and for the foreseeable future, commercial SATCOM is used by the DoD to fill gaps in *coverage* and

Table 1 The roles of the components of the MILSATCOM architecture.

| | Narrowband | Wideband | Protected |
|---|---|---|---|
| MIL UHF | Yes | No | No |
| MIL SHF | Capable of | Yes | Somewhat |
| MIL EHF | Yes | Planned | Yes |
| GBS | No | Yes | No |
| Commercial | Yes | Yes | No |

[6] From the Forward to [35], written by Howell M. Estes, III, General, USAF, Commander in Chief.

[7] ibid.

*capacity* in applications that can forego *protection*, recognizing that *access and control* may not be completely in the hands of military personnel. It can be argued that military use of commercial SATCOM has positive impacts on *interoperability* and the DoD's wide use of INMARSAT could be used to support that argument [18], [48]. The *quality of service* (e.g., availability, delay, bit error rate, etc.) required of a particular SATCOM circuit depends on the nature of the communications traffic it is intended to carry; the wide range of commercially available SATCOM services allows, in theory, a cost effective matching between quality of service and the priority of the traffic. Finally *flexibility* largely refers to the ability to respond effectively in contingency situations, and keep pace with and utilize technological improvements; this is an area in which commercial SATCOM excels.

## Early Commercial Augmentation of Military SATCOM

Military use of commercially-owned SATCOM resources is not new. Very early in its use of SATCOM, the DoN (and DoD) learned the value of commercial augmentation. This section provides a brief historical perspective.

### *IDCSP, TACSAT and LES*

The Initial Defense Communications Satellite Program (IDCSP) provided DoD with its first quasi geosynchronous SATCOM system in June, 1966 [14]. IDCSP was followed by the TACSAT Program which developed and tested tactical SATCOM concepts for all US military services. TACSAT-1 was launched by the USAF Space and Missile Systems Organization (SAMSO) in February, 1969. The DoN's first use of SATCOM came in June, 1970 when residual IDCSP and TACSAT assets were made available to the USN by the direction of the JCS [13]. Recognizing the USN's unique communications requirements, the Secretary of Defense approved the DoN's UHF Fleet Satellite Communications (FLTSATCOM) Program in September, 1971. Three months later, in December, 1972, TACSAT-1, located in the Pacific Area, failed. At that time, the DoN was using the UHF channels on the Lincoln Labs Experimental Satellite LES-6 for coverage in the Atlantic. However, in December, 1972, it was anticipated that (1) LES-6's useful life would end in September, 1973, and (2) the first FLTSATCOM satellite would not be available until December, 1978. Therefore, with the loss of TACSAT-1, the DoN was faced with a six-year period in the Pacific, and a potential five-year period in the Atlantic, during which *no* UHF SATCOM relay would be available.

### *GAPFILLER*

To minimize the gap in space segment continuity, the DoN decided, in late December, 1972, to initiate efforts to *lease* UHF SATCOM services. A contract for two-ocean coverage (Atlantic and Pacific) was signed with COMSAT General in March, 1973, and modified in September, 1976 to include coverage of the Indian Ocean. This UHF capability was provided on the Maritime Satellites (MARISAT). The leased UHF services (dubbed GAPFILLER by the DoN; a.k.a. "GAPSAT") commenced for the Atlantic in March, 1976 (at which time LES-6 was deactivated – 2 ½ years *later* than anticipated), for the Pacific in June, 1976, and for the Indian Ocean in September, 1976. This interim capability was phased out by the FLTSATCOM satellites, the first of which was launched into orbit in February, 1978, ten months *earlier* than originally anticipated.

### *LEASAT*

The LEASAT series was developed as a commercial venture to provide dedicated communications services to DoD. The program was a result of Congressional reviews in 1976 and 1977 which advised increased use of leased commercial SATCOM by DoD [14]. Owned by Hughes Communications, the LEASATs were designed to provide global UHF communications to all DoD air, sea, and ground forces although the system's primary user was the DoN. The first four LEASATs were launched between August, 1984 and August, 1985 from NASA's Space Shuttle. Hughes was paid $84M per year for each operational satellite. At the end of each satellite's 7-year design life, DoN had the option of purchasing it for $15M but elected not to do so.[8]

### *UFO and Commercial Practices*

In 1988 the DoN undertook the UHF Follow-On (UFO) program to replace the LEASATs and (eventually) the FLTSATs. This highly successful program is "commercial like" in that it has pioneered the utilization of the following commercial practices in the development and fielding of a DoD-owned SATCOM system:

- Firm fixed price for delivery of each spacecraft on orbit,[9]
- Guarantees of payload performance once on-orbit, and
- Commercial insurance in case catastrophic loss of a spacecraft.

All of these practices reduce the Government's risk, while the third one also reduces the contractor's risk.

## Rapid Acceleration of DoD Use of Commercial SATCOM in the 1990's

Desert Shield/Desert Storm in 1990/91 accelerated the DoD's use of commercial SATCOM services. The DoD and the Coalition Allies used a combination of US, NATO, and commercial telecommunications assets to support their operations. However, Desert Storm also served to highlight the shortfalls of the DoN's *wideband* SATCOM capabilities in 1990/91. At that time, it was impossible to deliver aircraft tasking orders (ATOs) and Joint Service Imagery Processing System (JSIPS, [15]) products to aircraft carriers and Aegis cruisers at sea in a timely manner via satellite [16]. The most

[8] All the GAPFILLERs and the LEASATs have been deactivated. As of this writing (Jan '99), all DoD's geosynchronous UHF SATCOM assets are Government-owned: FLTSATs 1, 4, 7 & 8, and UFOs 2 through 9.

[9] UFO prime contractor Hughes also contracted for commercial launch services.

commonly used method of ATO delivery to aircraft carriers in Desert Storm was via computer disks which were ferried from shore via helicopter or fixed wing aircraft. This experience accelerated the deployment of military SHF SATCOM terminals on USN aircraft carriers. It also led directly to the initiation of the Challenge Athena project by the DoN, and the DoD's Global Broadcast Service (GBS), both of which involved heavy leverage of commercial SATCOM technologies and services. In addition, INMARSAT terminals have since been installed on virtually *all* Navy ship classes.

### *INMARSAT*

The DoN purchased over 1.5 million minutes of INMARSAT air time in 1994, and over 2 million minutes in 1995 for voice and narrowband data services (up to 9.6 or 14.4 kbps depending on individual equipment) [17]. By 1996, INMARSAT A terminals were installed on over 200 Navy ships in all major ship classes [18]. INMARSAT A provides a ship with a single analog telephone circuit worldwide except at extreme latitudes. The DoN plans to upgrade INMARSAT A to INMARSAT B terminals on many ship classes. This will give a ship a digital phone line at up to 64 kbps, also with worldwide coverage except at extreme latitudes. (Motorola's Iridium system would give improved coverage, adding the polar regions, with voice and narrowband data throughput capabilities - 2.4 to 4.8 kbps.)

### *Challenge Athena*

Challenge Athena (CA) is the DoN's name for its program that has installed large (9-foot diameter) C-band (6/4 GHz) SATCOM antennas on aircraft carriers and command ships throughout the fleet. This wideband connectivity, at data rates up to T1 (1.544 Mbps), is provided via C-band transponders on several commercial satellites. An excellent detailed description of the CA Program, from its inception in August, 1992, through mid-1995, is given in [19]. In 1999, CA has surpassed military SHF SATCOM as the principal wideband SATCOM service for forward-deployed aircraft carriers and command ships.[10] A discussion of current efforts to address international frequency management issues for CA is given below.

### *DBS, GBS Phase I, JBS and BC2A*

The emergence of the high throughput (23-30 Mbps), small antenna size (18 inches) and affordable cost (~$300.00 initially) of the Direct Broadcast Service (DBS) receive equipment that emerged in the early 1990's did not go unnoticed by the DoD. In November, 1994, Hughes installed a DirecTV® DBS system aboard the aircraft carrier *USS Abraham Lincoln* (CVN 72) as a technology demonstration [52]. The system installed on *Lincoln* was identical to the commercially available one except for the addition of an antenna pointing and tracking system which allowed reception while the ship was underway off the coast of California. In addition, a fiber optic cable was used to route the 500 MHz wide L-band block (950-1450 MHz) from the low-noise-amplifier/block-downconverter (LNB) at the antenna to the Ship's Information, Training and Entertainment (SITE) TV station. Although the pointing and tracking system was less than adequate to compensate for the full range of ship's motion, and although there was a "learning curve" which included loss of signal due to "ship vibration from catapult shots and, depending on ship's heading, aircraft passing through LOS signal path during recoveries [52]," the concept was proved. It was sufficient to *demonstrate* that it was possible to send digital data (in this case commercial TV) to an aircraft carrier at sea at rates more than an order-of-magnitude higher than any previous, or then planned, military SATCOM system.

Also in the fall of 1994, the Operational Support Office (OSO) participated in a series of JCS-sponsored efforts to capitalize on, and adapt the DBS concept for military use. The first was Radiant Storm,[11] funded by the USN Tactical Exploitation of National Capabilities (TENCAP) office, which demonstrated the simultaneous transmission of actual military data (encrypted with a KG-194 and sent at 1.536 Mbps) and commercial television signals (Cable News Network - CNN - considered "soft intelligence") over the Hughes DBS-1 satellite.

Subsequently, OSO helped with a host of wideband SATCOM broadcast communications technology demonstrations coordinated under the Joint Warrior Interoperability Demonstration in August/September, 1995 (JWID'95). The JWID'95 trial version of the Global Broadcast Service (GBS) demonstrated the capability of moving source video, audio, and data to over 35 receive locations in the continental US (CONUS) and Hawaii using multiple data transmission protocols including MPEG-II, IP and ATM. The satellites employed in these initial GBS demonstrations included NASA's experimental Ka/K-band Advanced Communications Satellite (ACTS) [20], [21] and the commercial Ku-band Telstar 401[12] satellite.

During JWID'95, one of the authors (Axford) flew in a USAF C-130 which had installed a 3-½ by 3-½ inch, 91-element, receive-only, K-band (20 GHz) phased array antenna ($G/T$ = -7.3 dB/K)[13]. This was used to implement a 1 Mbps "GBS-like" demonstration link to the C-130 while in flight within the footprint of ACTS' "East-18" spot beam[14] which covers much of Southern California. Using a commercial-off-the-shelf (COTS) SATCOM modem and other non-developmental equipment, personnel in the aircraft were able to simultaneously receive classified intelligence data and sub-broadcast standard (but watchable) live CNN audio/video.

It did not take long after JWID'95 for the first step of a major GBS acquisition program to be taken: the GBS Mission Need Statement (MNS) was delivered to the Under Secretary of Defense (Acquisition and Technology) by the Joint Chiefs of

[10] Σ (CA bandwidth to ships) > Σ (SHF bandwidth to ships).

[11] Radiant Storm's setup and results are documented in [23].

[12] Subsequently destroyed by a magnetic storm Jan 1997.

[13] This array was fabricated by Boeing under contracts with the NASA Lewis Research Center (LeRC) and USAF Rome Lab.

[14] EIRP ~60 dBW.

Staff on 14 November, 1995 [21]. Nor did it did not take long for OSO to have an opportunity to insert GBS into an actual military operation. In December, 1995, President Clinton ordered the deployment of US troops in support of Operation Joint Endeavor in Bosnia. The Bosnia Command and Control Augmentation (BC2A) Initiative[15] employed the GBS concept to provide Joint Endeavor forces with a Bosnia-specific military information (video and data) delivery service via the transatlantic commercial Ku-band satellite Orion-1 located at 37.5° W. This broadcast is known as the Joint Broadcast Service (JBS)[16] and it has included installations of commercial-off-the-shelf (COTS) 1.2-meter stabilized Ku-band antennas on USN ships for reception while deployed in the region (Mediterranean and Adriatic). JBS is the operational portion of GBS Phase I. GBS Phase I enables experimentation, training and concept of operations (CONOPS) development via commercial Ku-band[17] coverage over CONUS [23], [24], [25], [26], [27], [28].

### *GBS Phase II*

The successes of JWID'95, JBS and GBS Phase I influenced DoD's decision to proceed with GBS Phase II and place steerable high power Ka/K-band transponders on UFOs 8, 9 & 10. UFOs 8 & 9 are already successfully in orbit, and UFO 10 is scheduled to be launched in the summer of 1999. Even after the dedicated military Ka/K-band GBS is fully operational, DoD will continue to lease Ku-band commercial satellites for GBS augmentation.

## Limitations of Commercial SATCOM

Commercial SATCOM can satisfy most of the seven KPPs listed above. However, commercial SATCOM systems lack the same degree of protection, survivability, and assurance of accessibility that can be provided by military systems. Jamming equipment that operates at civilian (and military) frequencies is readily available. Commercial SATCOM systems, regardless of the frequency spectrum used, are not currently constructed to counter DoD-recognized manmade threats.[18] Also, records of billing and registration functions, routing and setup of connections, can provide data that, properly analyzed, will expose the user's location, capabilities, and/or intent. Analysis of traffic patterns can disclose operationally significant activity even if the information itself remains encrypted.

Considering commercial SATCOM's limited protection and less-than-assured access & control, there are certain circuits which are never candidates for commercial routing. Depending on the operational scenario and the anticipated threat, many circuits which are candidates for commercial SATCOM may use MILSATCOM or commercial SATCOM. MILSATCOM-only circuits typically go to the protected systems (e.g., EHF) and/or to systems for which all forces have capability (e.g., UHF). The remaining circuits will be allocated to other MILSATCOM systems and/or commercial SATCOM systems typically dictated by capacity and geographical & time-of-day coverage requirements.

### *Vulnerabilities*

A thorough discussion of the specific vulnerabilities of commercial SATCOM systems from a military perspective is beyond the scope of this paper.[19] Nonetheless, operational security (OPSEC) is just as important to survival in business as it is to the (literal) survival of military troops. A viable SATCOM business venture cannot leave its satellites vulnerable to unauthorized commands that malicious parties might send to, say, disturb the spacecraft's attitude thereby mispointing its antennas. To prevent such occurrences, the telemetry, tracking and command (T, T & C) links of commercial communications satellites are routinely encrypted. This is an example of a vulnerability shared by both the military and commercial concerns in which commercially-applied countermeasures may be adequate for military purposes. Determinations must be made on a case-by-case basis.

## Spectrum Management

A key aspect in the development and procurement of any communications-electronics (C-E) equipment is *frequency supportability*.[20] In an effort to keep up with the ever-increasing pace of technological developments, recent DoD acquisition reforms[21] have significantly reduced the minimum time between the release of a request for proposals (RFP) and the actual fielding of new C-E equipment. An unintended result is that the acquisition cycle time is now often less than the time required to perform the tasks that will ensure frequency supportability.

The international management of radio frequencies for telecommunications services is established by treaty [5] through the International Telecommunications Union (ITU) [47]. Because all military and commercial SATCOM systems may impact communications systems outside our national borders, they must be coordinated through the ITU.

The international frequency coordination process has yet to undergo streamlining similar to that which DoD acquisition reforms have accomplished. Until it does (if it does), some interesting spectrum management challenges have been added to those already faced by DoD SATCOM terminal procurement office program managers. An excellent comprehensive treatment of the spectrum management issues associated with MILSATCOM architectures is presented in [31]. Illuminating overviews of spectrum management issues from the perspective

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15 USCINCEUR/DARPA/DISA Joint Project Office (JPO).

16 Originates in the Pentagon and is ongoing as of this writing.

17 Currently using SBS 6 at 74°W.

18 Manmade threats are listed on pp. 2.2-2.7 of [35].

19 See [43] for some examples.

20 Frequency supportability includes obtaining spectrum certification and frequency assignment, obtaining permission to operate a terminal within a host nation, and the ability to operate without causing or receiving interference. [31]

21 In particular, those acquisition reforms that encourage the use of commercial-off-the-shelf (COTS) equipment.

of a USN SATCOM terminal procurement office program manager are given in [33] and [34].

*WRC-2000 & Maritime Use of the 6/4 GHz Band for SATCOM*

This sub-section focuses on a specific spectrum management issue currently being addressed by the Space and Naval Warfare Systems Command (SPAWAR) on behalf of the DoN. Much of the material is drawn from [45].

Challenge Athena (CA) was originally developed by the Operational Support Office (OSO) in 1992 for the Chief of Naval Operations (CNO) as a quick-reaction demonstration program in response to the urgent needs for greater SATCOM capacity for USN ships that arose in 1991 during Desert Storm [16], [19]. Responsibility for the program was transferred from OSO to SPAWAR PMW 176-4 (Wideband RF Systems Branch, Joint Maritime Communications Systems (JMCOMS) Division) in 1995, following the highly successful CA-I and CA-II demonstrations. While developing the follow-on CA-III, PMW 176-4 learned that no frequency allocation requests had ever been filed for the commercial-of-the-shelf (COTS) C-band (6/4 GHz)[22] shipboard earth terminal equipment that OSO had procured for the previous CA demonstrations. Since PMW 176-4 was interested in maturing CA from a demonstration to a viable, long-term Navy program, a Stage-II frequency allocation request, Form DD-1494, was prepared and submitted in accordance with applicable directives. It was during this process that the breadth and complexity of regulatory issues associated with implementing CA became fully apparent.

The ITU has allocated C-band for the Fixed Satellite Service (FSS) and the point-to-point, line-of-sight microwave Fixed Service (FS) throughout the world. Maritime use of a broadband FSS-like service (i.e., CA) does not fit neatly into any class of service currently defined by the ITU. CA is perhaps best described as a Maritime Mobile Satellite Service (MMSS), a subset of the Mobile Services (MS). However, there is no ITU MS, let alone MMSS, allocation in C-band. Therefore, from a regulatory perspective, CA's operation must be done on an experimental, not-to-interfere basis, without protection from electromagnetic interference (EMI) caused by pre-existing users of the band (FS and FSS). In the US, the allocation issue is further complicated because here C-band is further allocated for *exclusive non*-government use and, accordingly, is regulated by the Federal Communications Administration (FCC) [31], [58]. Government use on an exceptional basis is possible, but it must be coordinated by the FCC and the National Telecommunications and Information Administration (NTIA) [31], [57]. Therefore, from a frequency allocation perspective, there are two sets of concerns for the CA program - International and National.

The stage II frequency allocation request submitted by PMW 176-4 in early 1996 was approved by the United States Military Communications-Electronics Board (USMCEB) JF-12 Working Group, the NTIA and CNO in late 1997. The approval was subject to the restrictions cited above and contained direction to demonstrate how sharing between the currently allocated services can be accomplished. Since 1996, PMW 176-4 has been actively engaged in ongoing efforts to build a case for sharing between the FSS-like MMSS and FS in the 6/4 GHz bands. Teamed with the Naval Electromagnetic Spectrum Center (NAVEMSCEN), DoD, NTIA, and the private sector, PMW 176-4 helped US delegates to World Radiocommunication Conference 1997 (WRC-1997) obtain an agenda item for WRC-2000[23], currently scheduled for May of 2000. Addressing the agenda item is the mechanism for international study of the issue. It also starts the process that can result in the changes to the frequency allocation tables required to permit protected use of C-band by "MMSS-like" users. Fortunately the DoN is allied in ITU-R Study Group 4-9S with the cruise ship industry, the oil industry (off-shore exploration and drilling), the Navy of Australia, Telenor of Norway, and other concerns in Brazil and Canada in its efforts to reach a satisfactory resolution in time for WRC-2000. It is worth noting that the cruise ship industry has many more C-band earth stations on board vessels (ESVs) than the US Navy does.

From a pragmatic perspective, ESVs operate in three distinct modes: (i) at sea, (ii) while stationary in port, and (iii) in-motion along designated sea lanes while approaching or departing from port. A testament to the progress made thus far by ITU-R Study Group 4-9S comes from the document "U.S. Preliminary Views on WRC-2000" which is available at [59]:

*"The U.S. considers that operations at sea (beyond the as-yet-to-be-determined distance for near-shore coordination) by earth stations on board vessels in the fixed-satellite service do not present potential for interference to terrestrial stations and need not be coordinated. Operations while these facilities are stationary in port are being coordinated in the U.S. as fixed-satellite earth stations. However, from a regulatory point-of-view, it has not yet been determined whether port-side operations will be considered as "fixed earth stations" or as "temporary fixed earth stations". Other technical and regulatory issues remaining for resolution concern the potential for interference between in-motion operations aboard ships that are underway between port and "at sea" (currently operated on a secondary basis) and terrestrial stations in the fixed service. This view is consistent with the work plan adopted for the Correspondence Group. (3 June 98)"*

Of considerable aid to ITU-R Study Group 4-9S has been the existing body of literature on frequency sharing and coordination procedures. This includes selections from the ITU-R SF Series of recommendations on frequency sharing between

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[22] More precisely: 5.925-6.425 GHz (earth-to-space) and 3.700-4.200 GHz (space-to-earth).

[23] **WRC-2000 Agenda Item 1.8**: "To consider regulatory and technical provisions to enable earth stations located on board vessels to operate in the fixed-satellite service networks in the bands 3 700 - 4 200 MHz and 5 925 - 6 425 MHz, including their coordination with other services allocated in these bands." The group assigned action on this agenda item is ITU-R Study Group 4-9S.

the FSS and the FS, the ITU-R P Series of recommendations on radiowave propagation (especially [60]), and Appendix 28 of the International Radio Regulations [61]. See also Chapter 11 of [62].

## Affordability

The "bottom line" is always a paramount consideration and the costs of commercial SATCOM services are high. Many recent studies have confirmed that, for comparable SATCOM services, the life cycle costs of directly leasing such services from the retail marketplace are more expensive than owning them or participating in an investment or operating "partnership" with commercial vendors [35]. For example, in [32] it is reported that "leasing costs for a commercial system are 2.5 to 4 times greater than the cost of acquiring and operating a commercial-like system."[24]

### *CSCI*

Military leasing of SATCOM has often been done at the individual unit level. Opportunities may have been missed to integrate multiple requirements and execute them in fewer, combined lease actions thereby realizing significant cost savings over multiple separate leases [35]. To implement this "volume discount" approach, the Defense Information Systems Agency's (DISA) Commercial Satellite Communications Initiative (CSCI) Management Office was established in 1994 as a "one-stop shop to support all warfighter commercial satellite communications requirements in either C-band or Ku-band." [29], [30]. It is CSCI's role to "shop around" for the lowest cost commercial SATCOM sources available for the DoD. In FY94 Congress appropriated \$20M to the Assistant Secretary of Defense for C3I for commercial SATCOM (\$9.5M for infrastructure and transponders, \$7.5M for terminal purchases and the remainder for operations, maintenance and training) [43]. Today CSCI buys \$200M of commercial satellite service annually and can lease up to 45 commercial transponders in C-band or Ku-band worldwide. Ideally, in addition to getting the best deals (10% to 20% below published tariff rates [30]), CSCI relieves the individual uniformed services from much of the "paperwork" associated with leasing domestic and international transponders.

### *Legislative Impediments and Disincentives*

"The Senate Report on the Fiscal Year 1998 National Defense Authorization Act (Senate Report 105-29) requested that the DoD consider the range of emerging commercial SATCOM systems as cost effective candidates for satisfying a number of DoD SATCOM requirements in a fiscally constrained environment. In addition the report asked the Department to consider new and innovative ways of acquiring these systems and to identify statutory, regulatory and policy impediments to their use to meet military needs."[25]

The study conducted by DoD in response to this Congressional direction considered several innovative acquisition approaches and concluded that most such strategies are variations of four fundamental approaches to acquiring commercial SATCOM [32]:

- direct purchase of hardware,
- lease of hardware,
- purchase of services, and
- equity investment.

In reviewing these acquisition approaches the study identified three regulatory or statutory provisions with a potential impact on innovative financing and procurement of commercial SATCOM. These were [32]:

- Office of Management and Budget (OMB) Circular A-76, which states that the government will not compete with its citizens;
- 31 U.S.C. 1341 (a)(1), also known as the Anti-Deficiency Act, which requires up-front obligation of funds to cover the maximum liability of the government under the contract, including termination liability; and
- The Miscellaneous Receipts Statute, which directs that all funds flowing into an Agency from contractors and non-governmental sources go into the general Treasury.

At the conclusion of the study, only the Anti-Deficiency Act remained as a potential disincentive.

From [32]: "The Anti-Deficiency Act affects procurement for commercial SATCOM services by requiring up-front funding to cover the Government's legal obligations. The Anti-Deficiency Act prohibits the obligation of funds in excess of the amount available in an appropriation. It also prohibits contracting for the payment of money in advance of an appropriation. A contract for services with a termination liability clause is an obligation of funds in an amount equal to the maximum liability of the Government including termination liability. These up-front funding requirements make it difficult to fit multiyear SATCOM leases, as one example, into tight Service budgets. Flexibility to obtain funding authority for commercial SATCOM product and or service leases would facilitate the use of innovative acquisition techniques." This conclusion could be extended to many other goods and services procured by the Federal Government.

### *Commercial Ka-Band Acquisition Initiative*

On 5 August 1998, the SATCOM Senior Steering Group (SSG) tasked the DoN and DISA to co-lead, with joint participation, the evaluation of commercial business cases for emerging commercial SATCOM systems in the Ka-band. This Commercial Ka-Band Acquisition Initiative, in addition to concentrating on the business aspects of leveraging future commercial SATCOM, will consider technical issues associated with commercial designs, potential frequency issues that could impact DoD, and the integration of commercial services into the emerging Wideband Gapfiller program and future wideband architectures [2], [35].

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[24] In [32] 'commercial-like' means "modified commercial systems and military systems with a high commercial parts content, that leverage commercial production lines and processes to obtain both commonality and cost-effectiveness."

[25] From the Executive Summary of [32].

In parallel with this effort, DoD will draft a Commercial Requirements Document for use as a "living document" to open communication with Industry. This document will identify business opportunities for the commercial sector (across the range of spectrum), and will highlight DoD services requirements that emphasize commercial augmentation of the DoD SATCOM architecture. The objective is for DoD to be able to influence system designs before they are finalized by increasing the vendors' understanding of DoD needs.

## Research Topics

This section lists some research topic areas that will benefit both commercial and military users of SATCOM.

### *Adaptive Interference Rejection Techniques*

As the spectrum becomes more crowded, EMI becomes a more common occurrence and therefore a bigger problem for commercial and military users alike. Military UHF SATCOM would benefit greatly from the incorporation of adaptive interference techniques (e.g., adaptive line enhancer) in the next generation of tactical UHF transceivers [63], [64].

### *Bandwidth Efficient Modulations*

As the spectrum becomes more crowded, it becomes important to generate more revenue in smaller amounts of bandwidth. This is even true in SATCOM. DoD is considering the use of bandwidth efficient modulations (8 PSK, 16 QAM) in its next generation of DoD-owned satellite, the so-called Wideband Gapfillers which will operate in the military X-band and the military Ka/K-bands.

### *FEC Coding Techniques*

Bandwidth is one precious communications resource and power is the other one. Coding techniques that reduce the $E_b/N_0$ required to maintain a given bit error rate (BER) are of great interest to military and commercial SATCOM systems engineers. Currently, the Office of Naval Research (ONR) is funding development work in Turbo Codes for naval applications. A widely held perception is that much work remains to be done to make Turbo codes implementable in practical hardware.

### *Additional Topics*

Among others, research in multiple access schemes, computer network security, SATCOM-tailored networking protocols (especially for multi-cast), and affordable electronic device technologies for multi-beam phased array antennas are all of great interest to the DoD.

## Conclusions

Commercial SATCOM will continue to play a significant role in the MILSATCOM architecture for the foreseeable future. However, the high lease costs and vulnerabilities associated with today's commercial SATCOM systems make it imprudent for DoD to develop an over-reliance on them. Perhaps DoD should eventually become fully *self-reliant* for its SATCOM requirements. Indeed, "DoD's large volume of need implies economies of scale that may make DoD-owned capability more cost-effective even when a similar capability is available on the market." [32]

With regard to the crop of emerging "Internet-in-the sky" and "multimedia" commercial systems, there is no consensus on what the potential total market is, let alone confident predictions of which particular offerings may become profitable [36], [38], [39], [40], [53], [54]. It is difficult to defend decisions that might lock DoD into single-vendor, proprietary solutions for SATCOM when those ventures may not even survive in the marketplace. Investments that develop military equipment that is compatible with, but not necessarily reliant on, open commercial standards can help DoD avoid "obsolescence through demise of market share."

Furthermore, while some commercial providers are moving towards satisfying a few unique DoD requirements, such as mobile netted communications, many military requirements -- especially protection, survivability, communications into low density areas (e.g., the open ocean), and interoperability with legacy systems -- have not been addressed by commercial SATCOM in the past and are not currently addressed by the emerging programs.

Nonetheless, DoD stands to gain through strategic partnerships with the commercial SATCOM industry and academic institutions. In the authors' opinions, these relationships should emphasize cooperation in research, development, test and evaluation. An honest evaluation of DoD's current rush to embrace COTS will reveal a mixed (and mixed up) experience. Consideration of the harsh realities of military requirements and environments "up-front" is, in our opinion, a more cost-effective strategy in the long run. The use of COTS may serve the worthy cause of rapid technology insertion, but the "oops factor" resulting from its misuse could be deadly in time of war [55].

The question of whether DoD should even maintain a core, DoD-owned MILSATCOM capability has been posed and studies have been conducted to answer it. In all cases, the answer, operationally, practically, and economically has been 'yes' [32]. Nonetheless, these studies do *not* support a conclusion of *no* DoD reliance on commercial SATCOM. As DoD transitions to the future architecture outlined in [2] and [35], the commercial market will continue to evolve. Commercial systems with increasingly capable technologies [56] will withstand and fail the tests of the marketplace. DoD must continue to monitor the market to determine to what degree it should rely on its own SATCOM assets. The "right mix" of commercial and military SATCOM will always be open to reevaluation. The methodologies proposed in [4] should be of some assistance in performing this ongoing task.

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